Agricultural Bulletin: IISS-1

Impact of the use of polluted irrigation water on soil quality and crop productivity near Ratlam and Nagda industrial area

Indian Institute of Soil Science
Nabibagh, Berasia Road, Bhopal – 462038

Agricultural Bulletin: IISS-1

Impact of the use of polluted irrigation water on soil quality and crop productivity near Ratlam and Nagda industrial area

Author
J.K. Saha
A.K. Sharma

भाकृअनुप
ICAR

Indian Institute of Soil Science
Nabibagh, Berasia Road, Bhopal – 462038

Correct citation : Saha J.K. and Sharma, A.K. (2006) Impact of the use of polluted irrigation water on soil quality and crop productivity near Ratlam and Nagda industrial area. Agricultural Bulletin: IISS-1, Indian Institute of Soil Science, Bhopal, pp. 26

Published by : Dr. A. Subba Rao
Director,
Indian Institute of Soil Science
Nabibagh, Berasia Road,
Bhopal – 462038
Madhya Pradesh

Authors : **J.K. Saha,** Senior Scientist (Soil Science), Division of Environmental Soil Science, Indian Institute of Soil Science, Bhopal
A.K. Sharma, Senior Scientist (Agricultural Economics), Indian Institute of Sugarcane Research, Lucknow

Year of publication : September, 2006

Foreword

With the rapid increase in population, demand for irrigation, human and industrial consumption of water has increased tremendously, thereby causing rapid depletion of fresh water resources. On the other hand, increased urbanization and industrialization is also generating considerable amount of wastewater. Such wastewater has been found to pollute groundwater bodies in and around many cities of the country rendering these to be unfit even for drinking. Also, water quality of rivers and lakes is getting deteriorated due to the indiscriminate disposal of such waste water, major proportion of which is untreated. In periurban areas particularly of semi-arid and arid regions, such polluted water is the only water source that supports the livelihoods of millions of poor people who irrigate high-value crops. However, use of such polluted water bodies as source of irrigation is posing a great threat to our precious land resources.

Ratlam and Nagda are cities of Madhya Pradesh, where considerable pollution of surface and groundwater bodies and also the agricultural lands using such polluted water bodies as source of irrigation to crops has been reported. Indian Institute of Soil Science carried out an investigative study to understand the nature and extent of water and land pollution in and around these cities as well as their effect on crop production. The study has generated useful information on the nature of contaminants, their effect on soil and crop as well as techniques to ameliorate the contaminated soil in order to enhance crop productivity.

For commendable efforts in generating information and technology, I congratulate the project staff associated with it. I hope that findings documented in this bulletin, will be useful to the farmers, various extension agencies, policy makers as well as various investigating agencies in the related areas.

Bhopal
September, 2006

A. Subba Rao
Director, IISS

Preface

Water is a precious resource of earth for sustenance of life, and only 3% of total water resources are non-saline fresh. Out of this only a very small fraction is present in rivers and lakes. However, about 57000 industries in India are discharging about 13468 million litres of wastewater per day (of which nearly 60% is treated) into rivers and lakes bodies, thereby polluting surface and groundwater bodies. Land and water bodies around several industrial areas in the country have been reported to be polluted by the toxic effluents. In Madhya Pradesh, Ratlam-Nagda industrial area has been identified as one of the 22 most polluted regions, where reports of land and water pollution appeared. In order to address the farming related issues, Indian Institute of Soil science carried out research under ICAR funded (through AP Cess scheme) Adhoc Research Project 'Environmental impact of the use of polluted ground water as irrigation on productivity and quality of crops in Ratlam-Nagda industrial area' during 2002-`05. Salient achievements of the project are presented in this bulletin.

Authors are extremely grateful to Indian Council of Agricultural Research for providing financial assistance for continuing research programme and also gratefully acknowledge the support and guidance of Dr. A. Subba Rao, Director, Dr. C.L. Acharya, Ex-Director, and all the Scientists of IISS, Bhopal for their valuable support, guidance and suggestions during the entire period of investigation. Our sincere thanks are also due to the staff of District offices of Govt. of M.P. at Ratlam and Ujjain for providing valuable information related to the study and villagers of the affected area for their immense help in conducting the experiments and providing relevant information. For successful completion of this project, authors express sincere gratitude to Mr. Kapil Ghewande and Mr. Vilas Patil, Senior Research Fellows and Technical and Supporting staff of Division of Environmental Soil Science.

Authors:
J.K. Saha (Soil Scientist &Principal Investigator)
A.K. Sharma (Agril. Economics & Investigator)

Introduction

Ratlam and Nagda city areas conjointly have been identified as one of country's 22 most severely polluted areas by Central Pollution Control Board. Industrial activities had resulted considerable deterioration of groundwater and surface water quality in these areas. Central Groundwater Board carried out hydrochemical studies in and around Ratlam dutring 2000-'01, which revealed that there is no improvement in the quality of ground water even about 5 years after closure of polluting industries. At Nagda, Chambal river has become polluted due to discharge of industrial effluents and farmers' of 14 villages, situated on the bank of Chambal river are highly concerned about their fertile cultivated lands loosing productivity due to use of polluted Chambal river water as irrigation.

Study area:

Ratlam:

The Ratlam- Nagda area has been classified as semi-arid and dry subhumid region receiving an average of 975 mm rainfall. The town of Ratlam is situated on Malwa plateau in north-west of Madhya Pradesh at 23°19′ N latitude and 75°03′ E longitude with an altitude of 495 m above mean sea level. Ratlam district consists of 22 villages covering a total of 102 Km^2. The agricultural land forms a major part (31%) of this area. Geologically, the entire area is underlain by deccan trap lava flows. Deeply weathered black cotton soil is up to 7-10 m; fractured basaltic sedimentation is at 20-25 m; further below is compact basalt.

The industrial area in Ratlam, located in north of the town, was developed in '70s. Major industries operating in the area were Ratlam Straw Board Ltd., Shree Sajjan Mills Ltd., Jayantvitamins Ltd., Sajjan India Ltd., Ratlam Alcohol Plant, Diesel Loco Shed Ltd., Maheshwari Proteins Ltd., and IPCA Laboratories. About 2000 cu.m. effluent per day used to pour through Dosinala which runs through the city southwards, finally draining into River Mahi. Majority of the industries were shut down by 1996 due to Supreme court order on the PIL filed on pollution issue.

Nagda:

Nagda town is 40 km away from Ratlam and falls in Ujjain district of M.P. The area has semi-arid climate with low rainfall leaving a perennial shortage of water in the area. The Nagda area is drained by river Chambal flowing south of Grasim industrial complex and Nagda town. This non-perennial river is also a source of water to the Grasim industrial cum residential complex and other ancillary units developed in the area. The common crops in the area are wheat, soybean, gram and maize. The geological formation of this area consists mainly of undisturbed hard deccan trap rocks supporting top soft soil.

The Grasim complex developed by the Birla Group is the major industry located on the north- west of Nagda town; which manufactures a variety of products including viscous rayon, caustic soda, liquid chlorine, carbon disulfide, etc. A few other ancillary industrial units, also, have developed to make various chlorinated products utilizing the chlorine produced by the Grasim. All these industrial activities result in a high volume of wastewater generation, which is carried away by a surface natural drain, leading to river Chambal. The length of the drain is about 5-6 km.

Irrigation water quality:

Ratlam:

Groundwater samples were collected from five villages of polluted area; namely, Ghatala, Bhajankheda, Jadwasa, Bhatuni, and Dosigaon as well as five villages of unpolluted area; namely Karmadi, Titri, Kalmoda, Kuwazagar and Salakhedi. Groundwater collected from the affected villages were yellowish to reddish brown colored (Photo 1) with spectrometric absorbance between 0.123 to 0.956 at 400 nm wavelength. There was a striking similarity in spectral absorbance characteristics (Fig. 1) as well as high contents of chemical oxygen demand (COD), sulphate and chloride between ground water of the affected villages and distillery effluent from a nearby Alcohol plant operating in nearby industrial area. This indicates that effluents from the Alcohol plant might be one of the sources of ground water contamination in the area. Fractured nature of basaltic sedimentation below the ground might have facilitated easy percolation of the effluent to contaminate groundwater. Color intensity of groundwater varies widely with tubewells in the same area and also with seasons.

Photo 1: Colored groundwater being used for irrigating the field in Jadwasa khurd village near Ratlam for sowing wheat crop

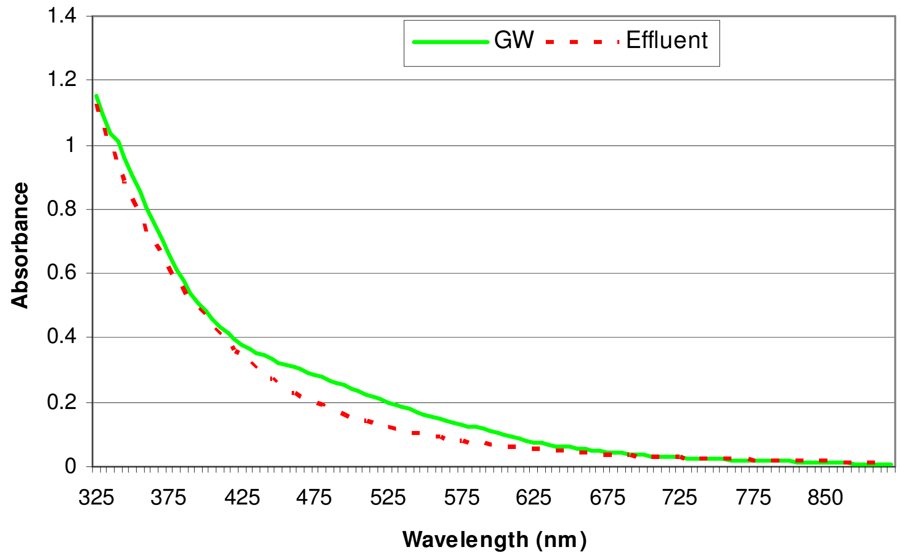

Fig. 1. Spectrometric absorbance of groundwater of polluted area and distillery effluent of Ratlam Alcohol Plant

While mean EC values of ground water of unaffected villages were in the range of 0.85-0.92 dS m^{-1}, the same in affected villages ranged from 1.49 to 4.50 dS m^{-1} with an overall mean of 2.84 dS m^{-1} (Fig. 2). Contents of sodium, sulphate and chloride in groundwater of affected villages were, respectively, in the range of 14.5 to 30.9 mM (mean 22.61 mM), 0.92 to 3.55 mM (mean 2.02 mM) and 6.16 to 35.88 mM (mean 2.83 mM). These values were, respectively, 348%, 288% and 364% more than the similar values obtained in groundwater samples of unaffected villages. The values of sodium absorption ratio (SAR) were considerably higher (range 3.36 to 12.29; mean 8.52) in ground water of affected villages as compared to the values (range 2.57 to 6.19; mean 3.88) obtained for unaffected villages. About 40% of the water samples in the polluted area can be categorized as having very high salinity (>2.25 dS m^{-1}) and sodium hazard (SAR > 9) and about 71% of the samples have potential for severe Cl^- hazard (>10 meq Cl^- L^{-1}) permitting their use as irrigation only in tolerant crops. Use of such bad quality irrigation water has caused disappearance of vegetable cultivation from the polluted groundwater area.

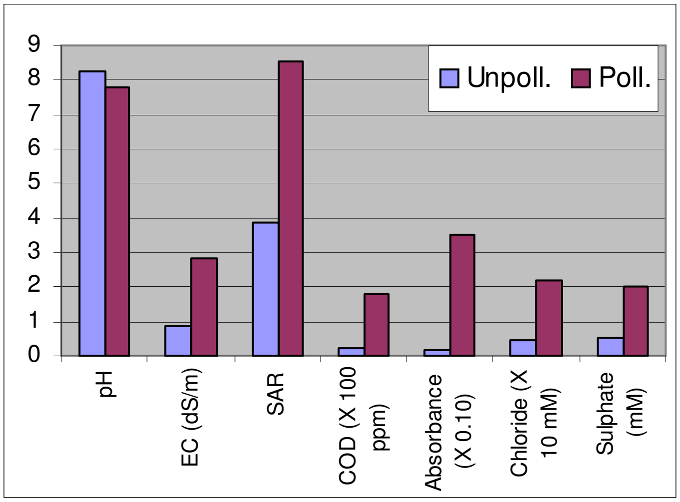

Fig. 2: Chemical properties of groundwater in affected and unaffected villages in Ratlam

Groundwater samples of polluted area contained, on an average, 9.1 µg/L Pb, 4.1 µg/L Cd and 18.5 µg/L Cu, which were more by about 162, 26 and 83% respectively over those in groundwater samples of unpolluted area (Table 1). Considering WHO limits for groundwater, samples from Bhajankheda, Jadwasa khurd and Dosigaon villages of polluted area contained unsafe levels of Pb and Cd. Two villages of unpolluted area also contained unsafe level of Cd in groundwater.

Table 1: Heavy metal contents (ppb) in groundwater of of Ratlam

Villages	**No. of samples**	**Pb**	**Cd**	**Cu**
Polluted area				
Ghatala	4	7.2	2.4	15.2
Bhajankheda	3	11.1	5.7	25.3
Jadwasa khurd	5	15.2	6.7	11.6
Bhatuni	5	5.4	1.2	27.6
Dosigaon	3	6.5	4.6	12.4
Mean		**9.1**	**4.14**	**18.46**
Unpolluted area				
Karmadi	3	4	2.6	6.5
Titri	3	2.9	3	8.8
Kalmoda	3	3.3	0.1	10.1
Kuwazagar	4	3.7	0.7	13.6
Salakhedi	1	3.4	0	10.1
Mean		**3.5**	**3.3**	**10.1**
WHO limit in drinking water		**10**	**3**	**2000**

Nagda:

A man made dam constructed at the upstream side of industrial area on the Chambal river withholds the fresh water during winter and premonsoon summer season for domestic and industrial use. During this period, downstream side of Chambal river carries mostly city and industrial effluents (Photo 2). Agricultural land of more than 14 villages at both side of the river are affected due to the use of effluent loaded river water for irrigation in winter season crops (Photo 3). Irrigation water (Chambal river) near affected villages had EC ranging from 2.38 to 4.11 (mean 3.56 dS m^{-1}) and contained 31.6 to 57.5 mM Na, 0.44 to 1.66 mM K, 3.54 to 4.32 mM Ca, 1.07 to 2.72 mM Mg, 2.93 to 6.76 mM SO_4^{-2} and 25.6 to 25.8 mM Cl^-, which were on an average, 4.7, 9.9, 7.7, 5.8, 1.8, 9.0, and 6.9 times more than the corresponding mean values obtained in irrigation water (ground water) in unaffected villages (Table 2). This shows that Chambal river water (at downstream of industrial belt) being used for irrigation is highly contaminated with soluble salts containing Na, Ca, Cl^- and SO_4^{-2}. The mean SAR value in Chambal river water was 5.1 times higher than the similar value obtained in ground water of unaffected villages. Irrigation water quality of Chambal river deteriorated at the downstream side of the river probably due to its gradual evaporation-concentration by solar radiation. According to established criteria, only salinity tolerant crops should be grown with such moderate salinity irrigation water considering the heavy texture of soil of the area.

Photo 2: A *nala* carrying industrial waste water is converging Chambal river, which is used for irrigation by farmers

Photo 3: Polluted chambal river water being used as irrigation by farmers of Juna Nagda village

Table 2: Chemical properties of irrigation water in some affected and unaffected villages in Nagda

	Nagda			
	Unpolluted area (Groundwater)		Polluted area (River water)	
	Max.	Mean	Max.	Mean
pH	8.12-8.91	8.46	8.17-8.3	8.18
EC (dS m^{-1})	0.38-1.12	0.758	2.38-4.11	3.56
Na^{+} (mM)	0.48-5.63	3.89	31.61-57.52	38.53
K^{+} (mM)	0.10-0.21	0.12	0.44-1.16	0.92
Ca^{+2} (mM)	0.27-1.40	0.65	3.54-4.32	3.79
Mg^{+2} (mM)	0.29-1.90	0.78	1.07-2.72	1.43
SAR	0.51-6.87	3.24	14.64-21.69	16.70
Cl^{-} (mM)	2.46-6.62	3.72	25.63-25.77	25.73
SO_4^{-2} (mM)	0.34-0.49	0.39	2.93-6.76	3.50

Changes in soil chemical properties due to continuous irrigation with polluted irrigation water

Ratlam:

For this study, surface layer (0-15 cm) soil samples were collected from about 10 farmers' fields from each of the polluted villages; viz., Sejawata, Jadwasa khurd, Malwasa, Jadwasa kala, Kaloli, Simlawada, Bhatuni, Bhajankheda, Ghatala and Dosigaon. For comparision, surface soil samples were also collected from nearby villages (Karmdi, Titari, Kalmoda, Kuwazagari, Salakheri, Kharakheri) where groundwater is reported to be unpolluted.

Soil samples collected from villages under groundwater polluted area in the month of February had, on an average, higher EC (4.5 times), SAR (4.6 times), organic C (1.5 times) and available K (22% more) as compared to the soils from unpolluted area (Table 3). Soils of Jadwasa khurd, Jadwasa kala, Bhajankheda, Ghatala and Dosigaon villages were more degraded as indicated by high EC and SAR. Such a build up of salinity could result in considerable damage to several crops (Photo 4). Available (DTPA extractable) Zn and Cu contents in soils were sufficient.

Table 3: Mean chemical properties of soils of polluted and unpolluted area in Ratlam

	Polluted area			Unpolluted area		
	Mean	Range	Standard deviation	Mean	Range	Standard deviation
pH (1:2 in water)	7.70	7.11 - 8.27	0.28	7.83	7.28 - 8.01	0.14
EC (mS/cm.)	1.83	0.49 - 5.01	1.00	0.41	0.25 - 0.76	0.21
SAR	3.98	0.69 - 27.12	4.72	0.86	0.69 - 2.65	0.86
Org. C (%)	0.70	0.44 0- 0.98	0.15	0.45	0.15 - 0.89	0.19
Avail. P (mg/kg)	18.70	16.0 - 22.4	1.65	26.64	11.5 - 43.7	7.95
Avail. K (mg/kg)	230.38	171.5 - 332.5	49.30	188.58	128.0 - 293.5	43.76

Photo 4: Polluted groundwater irrigation caused rotting of onion plant

Soil solution of affected villages, in general, had significantly higher concentration of Na^+ (9.7 times), Ca^{+2} (1.9 times), Mg^{+2} (1.8 times), Cl^- (12.5 times), SO_4^{-2} (4.8 times) and HCO_3^- (2.3 times) than those of unaffected area (Fig. 3). Concentration of K was similar but concentration of NO_3^- was more in soil solution of unpolluted area. Among the villages of affected area, Jadwasa khurd recorded maximum concentrations of Na^+, Cl^-, SO_4^{-2} and HCO_3^- in soil solution. Sodium, Ca, Mg and K constituted about 60, 28, 11 and 1% of the major cations; while, Cl^-, SO_4^{-2}, HCO_3^- and NO_3^- constituted about 60, 10, 11 and 19% of the major anions in soil solution of affected villages. Similar values in unaffected villages were 38, 43, 16 and 3% for cations and 12, 18, 12 and 58% for anions respectively. Thus, considerable accumulation of salt ions, particularly chloride and sulphate of Na in soils has been observed due to continuous irrigation with polluted ground water.

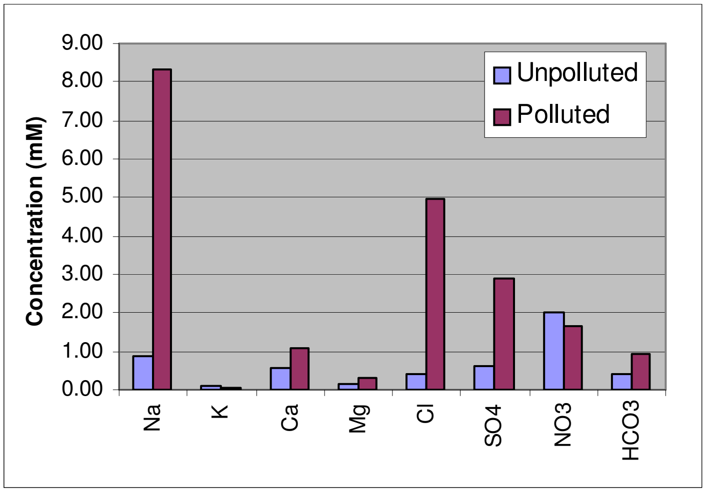

Fig. 3: Concentration of major ions in soil solution of Ratlam

Nagda:

Surface layer (0-15 cm) soil samples were collected during the month of February from about 10 farmers' fields from each of the Nine polluted villages; viz., Takkarwada, Old Nagda, Parmerkhedi, Bhagatpuri, Batisuda, Atlawada, Gidgarh, Nepania and Kilodiya situated at both side of Chambal river downstream side of industrial area. For comparison, surface layer samples were also collected five nearby villages, namely; Dabari, Banbuna, Makla, Rupata and Jalodiya (unpolluted area) using groundwater for irrigation.

Results (Table 4) indicated that soils of polluted area had EC ranging from 0.35 to 12.90 (mean 4.03 mS/cm); SAR ranging from 0.45 to 75.97 (mean 19.31). Mean EC and SAR values in soils of polluted area were respectively about 9.1 and 12.3 times higher than the corresponding mean values obtained for unpolluted area, indicating considerable salinity build up in the soils of polluted area due to irrigation with polluted Chambal river water (Photo).

Table 4: Mean chemical properties of soils of polluted and unpolluted area in Nagda

	Polluted area			Unpolluted area		
	Mean	Maximum	Standard deviation	Mean	Maximum	Standard deviation
pH (1:2 in water)	7.69	7.10 - 8.50	0.30	7.96	7.83 - 8.32	0.20
EC (mS/cm.)	4.03	0.35 - 12.90	3.10	0.44	0.25 - 1.32	0.52
SAR	19.31	0.45 - 75.97	20.70	1.57	0.53 - 2.43	0.69
Org. C (%)	0.67	0.29 - 0.99	0.20	0.53	0.33 - 0.75	0.11
Avail. P (mg/kg)	18.48	14.9 - 23.0	2.16	11.35	5.9 - 22.3	4.24
Avail. K (mg/kg)	270.00	145.5 - 454.0	88.03	177.10	110.0 - 300.5	45.95

Salinity build-up in the soils of villages Old Nagda, Parmerkhedi, Bhagatpuri, Atlawada, Gidgarh, and Kilodiya were very high. There were clearly visible salt deposits on the surface of some of these soils (Photo 5). Such a high salt accumulation (mainly of chloride and sulphate of sodium) resulted in poor germination of seeds and growth of wheat and vegetable crops. Analysis of wheat plant samples collected from these polluted area also indicated accumulation of Na which had a strong correlation between Na in soil solution. Such Na accumulation in soil resulted decrease in Ca and Mg uptake by wheat plant. Significant negative correlation was observed between SAR and Ca/Na ratio (r = -0.47**) and Mg/Na ratio (r = -0.39*) in wheat plant tissue. Mean organic C, available P and available K contents in soils of polluted area were respectively 26%, 63% and 52% more than the corresponding mean values obtained for unpolluted soils.

Photo 5: Salt accumulation in soils of wheat field irrigated with polluted Chambal river water

Mean ionic strength in saturation extract was about 70.1 mM which is about 18.5 times of the mean value obtained for unpolluted soils. Mean concentrations of major cations, viz., Na, K, Ca and Mg in the soil solution extracts of polluted soils were 41.4, 0.15, 2.56 and 0.49 mM which were respectively about 25.6, 2.0, 7.8 and 3.5 times more than the similar values obtained for unpolluted soils. Mean concentrations of major anions, viz., Cl^-, SO_4^{-2}, HCO_3^- and NO_3^- in the soil solutions of polluted soils were 2.55, 20.59, 1.49 and 0.61 mM which were respectively, 10.7, 40.8, 2.4 and 0.8 times of the similar values obtained for unpolluted soils (Fig. 4 & 5). Results thus indicate that soils of the polluted area have been severely contaminated with sulphate and chloride salts of sodium.

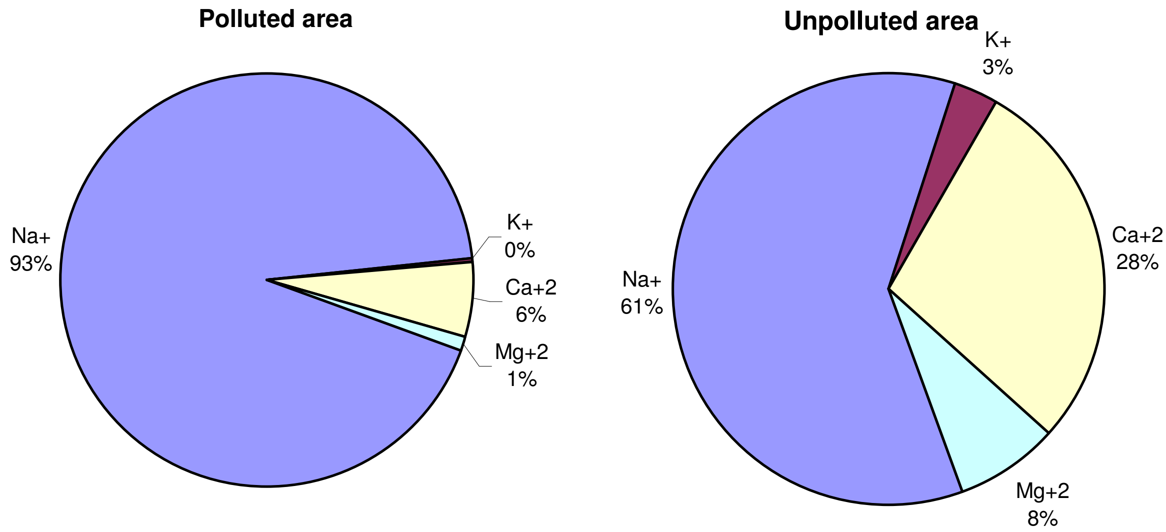

Fig. 4: Proportional distribution of major cations in soil solutions of Nagda study area

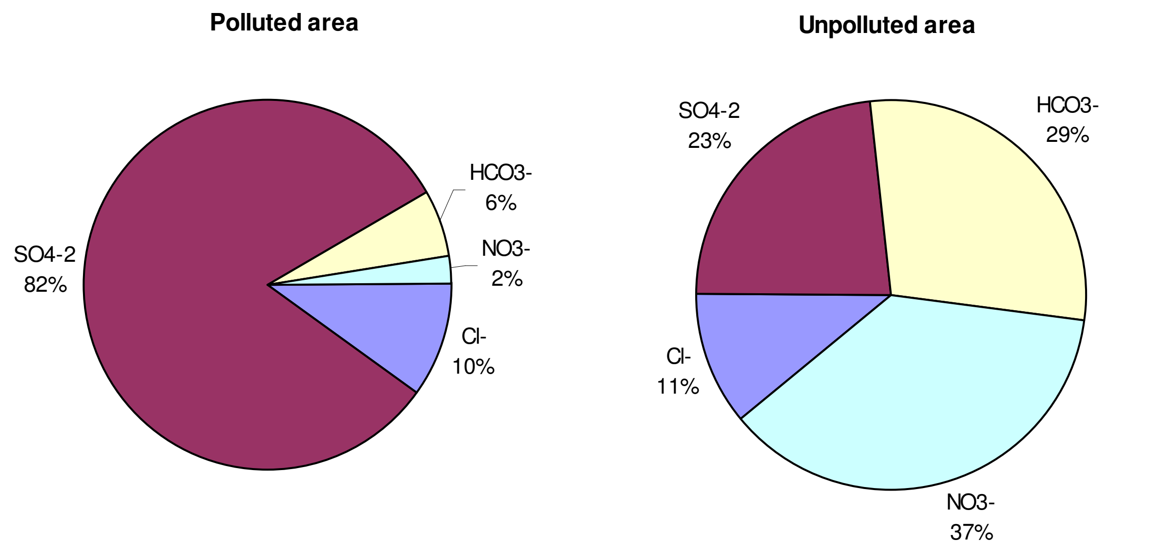

Fig. 5: Proportional distribution of major anions in soil solutions of Nagda study area

Ground water salinity in villages near Nagda industrial area

Average EC value of the groundwater in villages at downstream side was higher than the same at upstream side (Table 5). The EC of groundwater samples in some of the tubewells of polluted villages has gone up more than 2.5 mS/cm, which indicates that effluents of industrial area might have contaminated not only Chambal river but also the groundwater in nearby villages.

Table 5: Electrical conductivity (mS/cm) of groundwater samples in some villages near Nagda industrial area

	No. of source	Mean
Upstream side		
Bhagatpuri	1	1.21
Bhatisuda	5	1.73
Pardhi	4	1.72
Nipania	1	0.94
Udaipura	2	0.77
Mean	***13***	***1.28***
Downstream side		
Old Nagda	1	1.21
Parmarkhedi	3	2.44
Gidgarh	1	1.12
Kilodiya	2	1.43
Mean	***7***	***1.55***

Effect of monsoon rainfall on soil salinity and sodicity parameters

Ratlam:

Soil samples were also collected in the month of April after a heavy shower in last week of March and also in the month of September after recession of monsoon from the same fields of affected and unaffected area as were collected in the month of February. Pre-monsoon shower in the last week of March raised soil pH of affected area by 0.73 unit, and decreased EC (by 71%) and SAR (by 26%) values (Fig. 6). Increase in pH might be due to removal of chloride and sulphate anions from surface layer. A laboratory experiment also indicated that pH is elevated considerably upon leaching of polluted soils; while EC decreased.

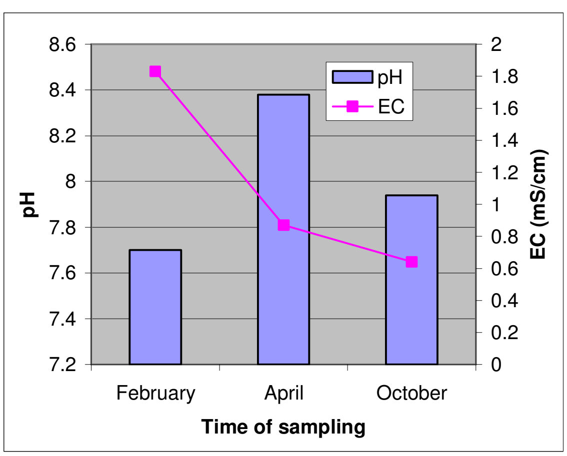

Fig. 6: Effect of time of sampling on pH and EC of polluted soils of Ratlam

However, rainfall of about 970 mm rainfall during the monsoon season of the year 2003 decreased mean pH by 0.44 unit, EC by 26%, exchangeable sodium percentage (ESP) by 69% and exchangeable sodium ratio (ESR) by 75% from the values obtained in the soils of affected villages collected in the month of April; thereby, resulting considerable amelioration of the polluted soils. This was due to considerable leaching of Na^+, Cl^- and SO_4^{-2} from the exchange complex.

Concentration of soluble Na^+, Cl^- and SO_4^{-2} in the soils of polluted area decreased by about 58%, 58% and 34% respectively; while, those of K^+ and Mg^{+2} increased by about 422 and 48.3% respectively over the corresponding values in premonsoon soils during monsoon period (Table 6). Concentrations of HCO_3^- and NO_3^- did not change significantly during this period.

Table 6: Changes in ionic composition of soil solution due to monsoon rainfall

	Polluted soils			**Unpolluted soils**		
	Pre-monsoon	Post-monsoon	**% Change**	Pre-monsoon	Post-monsoon	**% Change**
Na^+	6.13	2.56	-58.34	2.30	1.58	-31.27
K^+	0.05	0.26	388.51	0.10	0.07	-29.63
Ca^{+2}	1.10	1.18	7.11	0.59	0.57	-2.63
Mg^{+2}	0.29	0.43	45.03	0.17	0.29	76.04
Cl-	4.99	2.11	-57.79	0.40	0.26	-34.78
SO_4^{-2}	0.88	0.58	-34.41	0.60	0.47	-22.27
NO_3^-	1.64	1.98	20.44	2.03	1.71	-15.56
HCO_3^-	0.91	0.86	-4.92	0.40	0.57	41.25

Nagda:

Precipitation during the monsoon season increased mean pH (by 0.21 unit) and decreased EC (by 88%), ESP (by 93%) and ESR (by 95%) in the soils of affected villages (Table 7). Monsoon rainfall reverted some of the soils, which developed sodicity due to use of contaminated groundwater, to normal category. This might be due to considerable leaching of Na^+ from the exchange complex.

Table 7: Changes in average chemical properties of soils of some polluted and unpolluted villages near Nagda Industrial area due to monsoon rainfall

	Polluted soils			**Unpolluted soils**		
	Pre-monsoon	Post-monsoon	**Change**	Pre-monsoon	Post-monsoon	**Change**
pH	7.90	8.11	2.71	8.29	8.18	-1.33
EC mS/cm)	4.44	0.52	-88.34	0.71	0.23	-67.54
SAR	24.03	1.71	-92.88	2.39	0.69	-71.16

ESP	31.18	2.28	-92.68	1.51	1.45	-3.84
Ion.Str. mM)	70.07	12.25	-82.52	3.78	3.63	-3.95
ESR	0.47	0.02	-95.05	0.02	0.01	-3.92

During the monsoon period, concentration of Na^+ in the soil solution of polluted area decreased by about 93%; while, that of K^+ increased by about 323% over the corresponding values in premonsoon soils. No significant change was, however, observed for Ca^{+2} concentration. Also, the infiltrating rainwater during monsoon resulted about 93% decrease in the mean SAR in the soil solutions of polluted area. Concentration of Cl^- and SO_4^{-2} in the soil solution of the polluted area decreased by about 35% and 90% respectively over the corresponding values in premonsoon soils; while concentrations of HCO_3^- and NO_3^- increased by respectively 21 and 55%.

Total heavy metal contents in soils

Ratlam:

Soils of polluted area contained, on an average, 83.5 ppm Zn, 57.9 ppm Cu, 1.72% Fe, 829.7 ppm Mn, 0.25 ppm Cd, 10.6 ppm Pb, 31.2 ppm Co, 108.0 ppm Cr and 56.8 ppm Ni (Table 8). These contents were, on an average, 54.3% (for Zn), 71.8% (for Cu), 50.3% (for Fe), 66.1% (for Mn), 44.2% (for Cr) and 66.7% (for Co) less than the their contents in soils of unpolluted area. However, contents of Pb and Cd were more in soils of polluted area. There was no difference in the content of Ni between the soils of polluted and unpolluted area.

Table 8: Total heavy metal contents in soils of polluted and unpolluted area of Ratlam and Nagda

	Polluted area				Unpolluted area			
	Ratlam		Nagda		Ratlam		Nagda	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Zn (mg/kg)	71 - 119	83.5	59 - 722	123.5	74-273	182.6	121 - 213	161.8
Cu (mg/kg)	47 - 73	57.9	46 - 155	77.4	99-401	205.1	103 - 263	142.4
Fe (%)	1.05 –2.30	1.72	1.03 - 3.28	1.77	1.31-6.09	3.46	0.58 - 4.03	2.36
Mn (mg/kg)	649 –1049	829.7	435 - 1591	844.5	974-4024	2444.8	1279 - 3380	1995.8
Cd (mg/kg)	Tr. - 1.1	0.25	Tr. - 0.8	0.2	Tr. - 0.20	0.01	Tr. - 1.5	0.3
Pb (mg/kg)	2.9 - 31.2	10.6	4 - 32	7.6	10 - 18	3.8	4.7 - 22	8.9
Co (mg/kg)	18 – 127	31.2	19 - 56	31.9	59 - 137	93.7	46 - 106	66.0
Cr (mg/kg)	76 - 255	108.0	63 - 143	81.2	103 - 277	166.5	156 - 336	206.2
Ni (mg/kg)	39 - 128	56.8	29 - 66	40.6	25 -138	57.2	71 - 148	95.5

Nagda:

Soils of polluted area contained, on an average, 123.5 ppm Zn, 77.4 ppm Cu, 1.77% Fe, 844.5 ppm Mn, 0.2 ppm Cd, 7.6 ppm Pb, 31.9 ppm Co, 81.2 ppm Cr and 40.6 ppm Ni (Table

8). These contents were, on an average, 23.7% (for Zn), 45.6% (for Cu), 25% (for Fe), 57.7% (for Mn), 51.7% (for Co), 60.6% (for Cr) and 57.5% (for Ni) less than the their contents in soils of unpolluted area. There was no difference in the contents of Cd and Pb between the soils of polluted and unpolluted area. This indicates that heavy metal accumulation might not have taken place due to continuous use of polluted irrigation water in Ratlam and Nagda area.

Effect of polluted water irrigation on growth of vegetable crop

A greenhouse experiment was conducted to study the effect of polluted irrigation water of both Ratlam and Nagda on a vegetable crop (Bhendi) grown on soils, collected from one location of unpolluted area and two locations of polluted areas of both Ratlam and Nagda.

Effect of polluted groundwater of Ratlam: Irrigation with polluted groundwater resulted reduction in plant height (24%), number of leaves (33%), number of flowers (28%) and dry weight of biomass (61%) as compared to those grown with unpolluted groundwater. Polluted groundwater application also caused severe shedding of leaves (Photo 6) and significantly reduced uptake essential plant nutrients like K and Ca as indicated by decrease in Ca/Na (66%) and K/Na (77%) ratios. Application of organic matter resulted increase in plant height (7%) and K concentration (15%) and decreased Na concentration in plant (15%) in the polluted-water irrigated pots. Thus, organic manure had been found to have potential to ameliorate the adverse effect of polluted groundwater on plant growth. As a result of application of polluted groundwater, there was, on average, 94% increase in EC, 297% increase in Na, 956% increase in Chloride, 22% increase in sulphate and 135% increase in SAR of soil solution.

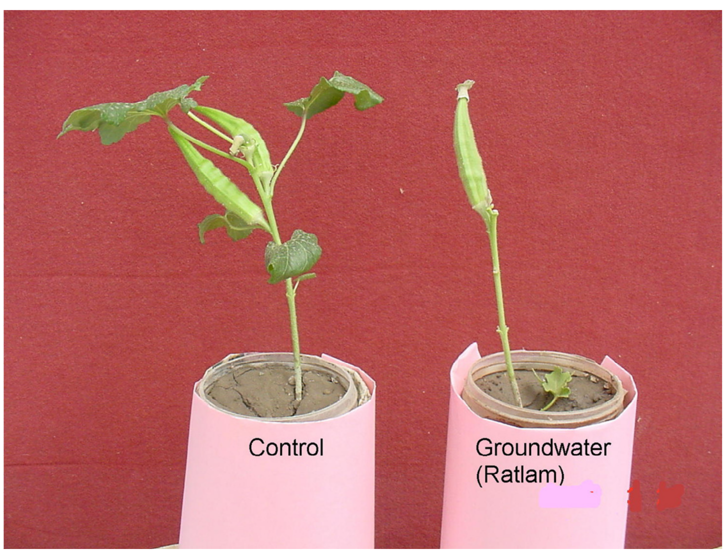

Photo 6: Polluted groundwater caused severe leaf shedding in Bhendi

Bhendi plants grown on polluted soils of Ratlam bore, on average, less (11%) numbers of flowers; had less (15%) biomass and contained higher (127%) Na, but lower Fe (25%) in plant tissue as compared to those grown on unpolluted soil.

Effect of polluted river water of Nagda: Plant growth parameters; viz., plant height, number of leaves, number of flowers and dry weight of aboveground biomass decreased significantly by 37%, 19%, 13% and 55% respectively due to use of polluted river water for irrigation (Photo 7). This also increased tissue concentration of Na (11 times) and decreased tissue concentration of essential nutrients like K (27%), Mn (34%), Zn (9%), Ca (10%) as well as Ca/Na ratio (92%) and K/Na ratio (93%). Dilution of polluted river water with unpolluted groundwater significantly reduced adverse impact of such polluted water on these plant growth parameters.

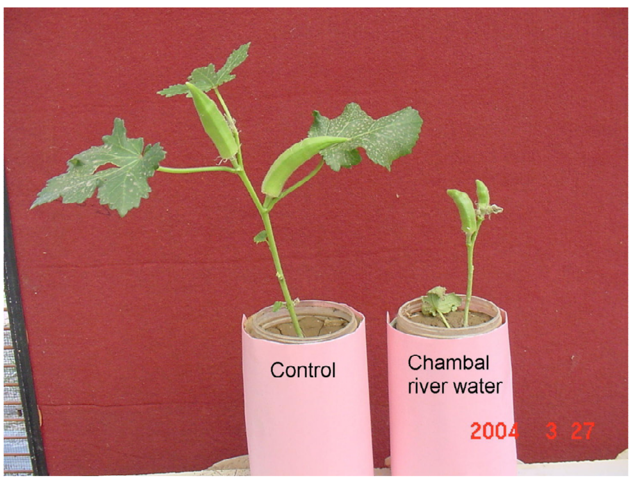

Photo 7: Growth impediment in Bhendi caused by polluted Chambal river water

Polluted river water resulted several fold increase in EC (153%), SAR (292%), Na (434%), Cl (482%) and SO_4^{-2} (21 times) in the soils. Such a degradation in soil chemical properties caused stunted growth with less number of leaves, flowers and reduced fruit size.

Plant height and number of flowers/plant were respectively about 12 and 14% lower in bhendi plants grown on soils collected from polluted area as compared to those grown on soils collected from unpolluted area. Further, Na concentration in plant tissue of bhendi grown on polluted soils were 28% more; whereas, tissue concentration of Mg, Ca, Fe, Mn and Cu were respectively, 25.7, 16.7, 18.1, 26.3 and 39.7% less as compared to plants grown on unpolluted soils, indicating a significant adverse effect on uptake of some important essential secondary and micronutrients.

Impact of groundwater pollution on the farmers' economy in Ratlam

Groundwater pollution has adversely affected the economic condition through changes in cropping pattern, reduction in crop yield, as well as reduced longevity of irrigation infrastructure. Area under vegetable and pulse cultivation has been severely reduced and the same under fallow has increased during rabi season as many farmers prefer to keep their land fallow instead of using polluted groundwater as irrigation. The yields of the traditional crops such as soybean, gram wheat, methi and garlic are less on the fields irrigated with polluted ground water (Table 9). Among vegetables, peas, onion, chilies, and lady'sfinger are the worst affected. Onion grown using polluted groundwater, has a very short keeping quality and starts rotting within 10-15 days after harvest; thus inflicting heavy economic losses to the farmers. Poppy cultivation, previously grown in wide area, has been abandoned because of drastic reduction in yield (Photo 8) and consequently the govt denotified the area for its cultivation. The iron pipes of the tubewell get rusted within 5 years; and therefore, the farmers are incurring losses on account of repair and maintenance of their irrigation infrastructure.

Table 9: Estimation of loss due to reduction of yield of crops

Crop	Av. Yield (qtls)		Yield reduction (qtls)	Price (Rs/qt.)	Loss per ha.
	Normal conditions	Polluted conditions			
Wheat	36	29	7	650	4550
Gram	12.5	9*	3.5	1400	4900
Soybean	15	11.5	3.5	1200	4200
Methi	18	12	6	1500	9000
Garlic	60	45	15	2000	30000

*When irrigation is given at later stages.

Photo 8: Symptom appeared in opium fruits in fields which was irrigated with polluted groundwater in the previous year in Jadwasa kala village

The drinking water source of the 8 villages has become unfit for human use. People are either forced to consume polluted drinking water or spend much effort and time in fetching potable water from a distance up to 3-4 kilometers. Approximately 300 mandays are used in each day in bringing potable drinking water from distant sources.

Investigation on suitable amelioration technique for improving production of soybean and wheat in polluted areas of Ratlam and Nagda

Field experiments were carried out in the polluted areas of both Ratlam (village: Jadwasa Khurd) and Nagda (village: Parmarkhedi) in order to find out effective strategy to enhance the yield of soybean (kharif) and wheat (rabi) which are predominant crops of these areas.

Soybean was grown in these areas with or without farmyard manure (FYM) and lime under rainfed condition. Results showed (Table 10) that soybean grain yield increased significantly due to application of FYM (@20 t/ha) at polluted area of both Ratlam (21%) and Nagda (31%). Application of lime (@ 5 t/ha), although resulted increase in grain yield at both place; its magnitude was not statistically significant. Maximum increase in soybean grain yield was observed in those plots where both lime and FYM were applied; the magnitude of increase being 27% in Ratlam and 35% in Nagda as compared to control.

Application of FYM alone or in combination with Lime also caused significant reduction in EC and SAR in upper 30 cm soil layer in both Ratlam and Nagda. Farmyard manure might have facilitated dissolution of native $CaCO_3$ (and thereby replacement of Na from exchange complex by Ca) and percolation of water down the profile resulting in decrease in EC and SAR values. Such effects on soil may be responsible for increasing grain yield of soybean in FYM treated plots.

Table 10: Effect of lime and organic matter on grain yield of soybean (q ha^{-1}) in polluted areas of Ratlam and Nagda

Treatments	Ratlam			Nagda
	Year 2004	Year 2005	Mean	Year 2004
Control	11.96	11.18	11.57	8.96
Lime	12.59	11.55	12.07	9.14
FYM	14.01	13.93	13.97	11.78
Lime + FYM	14.93	14.37	14.65	12.14
CD5%	1.70	2.06		2.14

Wheat crop was grown with polluted groundwater in Ratlam and polluted Chambal river water in Nagda after soybean crop. Application of FYM to previous crop increased grain yield of wheat significantly over control at both Ratlam and Nagda (Table 11); the magnitude being more at Nagda (21%) as compared to that obtained at Ratlam (15%). Application of straw mulch, though resulted improvement in yield, the increase was not statistically significant. Similarly, lime application slightly improved wheat grain yield only at Ratlam, though magnitude was not statistically significant.

Photo 9: Abundant growth of wheat crop in organic manure and lime amended plot (right) vis-à-vis less crop growth in no amendment control plot (left) in polluted groundwater irrigated experiment in farmers' field at Jadwasa Khurd (Ratlam)

Table 11: Effect of lime and organic matter on grain yield of wheat in polluted areas of Ratlam and Nagda

Treatments	Ratlam	Nagda
Control	41.90	38.78
Straw mulch	46.53	43.27
Lime	45.24	38.03
Lime + straw mulch	47.21	41.09
FYM	48.13	46.87
FYM + straw mulch	48.30	46.80
FYM + Lime	48.12	46.12
FYM + Lime + straw mulch	48.57	46.87
CD5%	5.82	6.21

Salient achievements:

- Groundwater of about 10 villages near industrial area at Ratlam is still polluted even after about 10 years of closure of the major polluting industries.

- Considerable contamination of groundwater with salt ions, particularly, Na^+, Ca^{+2}, Cl^- and SO_4^{-2} has been observed in groundwater near Ratlam industrial area.
- As a result of the use of such polluted groundwater, vegetable cultivation has been severely affected and crop yields have been reduced.
- Chambal river water has been severely polluted with industrial effluents at Nagda and contains high amount of salts, particularly chloride and sulphate salts of sodium with high SAR values.
- Irrigation with these polluted water resulted development of salinity and sodicity in soils at both the places. In Ratlam, dominant salt ions were Na^+ and Cl^-; whereas, in Nagda, Na^+ and SO_4^{-2} were dominant ions in soil.
- Salt ions get percolated with rainwater during monsoon season resulting in amelioration of the polluted soils of both of these two areas to a considerable extent. However, such removal of salt ions down the profile through rainwater in the polluted soils of Ratlam causes rise in pH, which is likely cause dispersion of soil particles and hence, reduction in infiltration capacity.
- Long-term use of polluted water for irrigation has not been found to significantly increase heavy metal contents in soils of both these areas.
- There is a significant increase in organic carbon content in the soils, particularly in Ratlam, where polluted groundwater is being used for irrigation continuously for years together.
- Presence of Cd and Pb beyond the safe limit (for drinking water) has been observed in tubewell water of several villages in both Ratlam and Nagda.
- Application of organic manure has been found to facilitate removal of salts as well as Na from exchangeable complex of soil by rainwater and also considerably improved soybean and wheat grain production in the polluted areas of both Ratlam and Nagda.

Results of practical utility:

1. *In-situ* conservation of rainwater in the agricultural field is very important for amelioration of polluted soils near industrial area of both Ratlam and Nagda, in terms of increasing productivity of crops.
2. Conservation of soil moisture during post-monsoon season highly desirable as this will reduce dependency on polluted water for irrigation.
3. Application of organic manure should essentially be made every year for enhancing amelioration as well as improving soil health.
4. In Nagda, groundwater may also be used so as to reduce dependency of polluted river water.
5. Cultivation Salt tolerant crops like wheat, barley, maize (kharif), sorghum, safflower, mustard and cotton may be practiced in the polluted areas
6. Although wheat is predominantly grown in the polluted areas, farmers' may be advised to grow salt tolerant and draught resistant (requiring less irrigation) varieties of this crop.

Photo 10: Luxuriant growth of cotton grown with polluted groundwater at Ratlam